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TNT Purification Studies
Task I - Comparative Cost Study of Purification Methods

RAD 240.10

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RAD 240.10

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This project was initiated to provide cost data for three most promising methods of purifying TNT. The methods considered include nitric acid cyrstallization (followed by isomer separation via the Brodie Process), magnesium sulfite (followed by recovery of MgO for recycle, and Sellite (followed by chemical recovery via the Sonoco Process).

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A major objective of this study was to determine whether further study of the nitric acid crystallization process was warranted. This comparative cost study includes capital, operating and raw material costs. Also considered are energy consumption and environmental factors.

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INTRODUCTION

Since World War I, alpha-trinitrotoluene (α-TNT) manufactured in the United States has been purified using the Sellite process. Sellite (sodium sulfite) reacts preferentially with the unsymmetrical TNT isomers present in the crude TNT to produce water soluble dinitrotolulene sulfonates. The aqueous solution, commonly referred to as red water, contains complexed alpha α-TNT and various oxidation products. The red water has a 20 to 35 percent solids content depending on the amount of water added to the purification process. Approximately one-half of the solids are organic.

Red water is extremely toxic to the flora and fauna of rivers and streams and, therefore, must be disposed of in such a manner that prevents stream contamination. The customary red water treatment approach is incineration. If the water is more dilute than 35 percent solids, it is usually concentrated via a multi-effect evaporator and then fed into a rotary kiln operating at 815°C - 950°C. The kiln is usually fired under oxidizing conditions so that all explosive material is combusted and the inorganic material oxidized to sodium sulfate. A significant quantity of fuel is required to evaporate the water in the solution fed to the rotary kiln. Also, the combustion gases from the kiln contain large quantities of NO_x which exceed permissable discharge standards. No demonstrated abatement technology has been applied to this effluent.

The ash which is produced in the kiln creates several problems. When land filled, the ash will produce a leachate which may contain nitroaromatics. The ash usually contains a significant amount of carbon which precludes its use for normal commercial purposes. Although the ash has been landfilled with plastic liners, a leachate may be produced and create a problem with time.

Some manufacturing facilities like Radford Army Ammunition Plant (RAAP) do not possess sufficient area for land filling of red water ash. The red water has instead been sold to paper mills to replace their sodium and sulfur losses. In most cases, the TNT facility pays for transportation costs as well as a small disposal fee. Although disposal by this means is advantageous, stricter pollution regulations have forced the paper mills to reduce their sodium and sulfur losses resulting in an unstable market for TNT red water. Further, red water has been proposed as a hazardous waste by the Environmental Protection Agency. Under this classification, severe transportation and plant operational restrictions preclude disposal via the paper mill route. Because of these concerns, a pollution free TNT purification process is imperative. This study, therefore, provides a cost comparison of the following three TNT purification processes; (1) Sellite, (2) magnesium sulfite and (3) nitric acid recrystallization.

CONFIGURATIONS AND DETAILED DESCRIPTION OF THE PURIFICATION SYSTEMS

After the nitration of toluene is complete, it is necessary to purify the crude TNT by removal of the unsymmetrical isomers and various oxidation products. The three most promising approaches for purifying TNT and processing the waste are as follows: (1) Sellite purification with chemical recovery via the Sonoco process, (2) magnesium sulfite purification with chemical recovery, and (3) nitric acid recrystallization with TNT recovery from the Isotrioil (nitric acid soluble nitrobodies) via the Brodie purifier.

Sellite Purification System

The approach first considered was the conventional Sellite purification of TNT with the Sellite being reclaimed and returned to the TNT process. The Sellite process employs an aqueous solution of sodium sulfite. Nucleophilic attack by the sulfite ion results in replacement of the meta nitro group. This reaction produces a water soluble dinitrotoluene sulfonate compound. The resulting aqueous solution is called red water because of its intense red color. Sellite also reacts with tetranitromethane (TNM) which is present in crude TNT and converts it to a water soluble sodium sulfite complex.

A purification material balance is shown in Figure 1. The red water wastes from the No. 1 Sellite washer will have a concentration of approximately 20 percent solids and require concentration to 35 percent via a multi-effect evaporator before being fed to the Sulfite Recovery Process (SRP). Figure 2 shows a conceptual diagram of the SRP. Aluminum hydroxide is added to the concentrated red water and the mixture incinerated in a furnace to produce sodium aluminate and sulfur dioxide. These chemicals are combined in a scrubbing tower to produce a 16 percent Sellite solution.

Magnesium Sulfite Purification System

The magnesium sulfite purification and recovery system is very similar to the Sellite system. The major difference between the sodium and magnesium processes is that magnesium sulfite possesses a low solubility in water. During TNT purification, magnesium sulfite must be continually added to the aqueous solution. This is accomplished by adding a magnesium sulfite slurry to a dissolver tank. The solution is pumped through hydrocyclones to remove solids prior to the solution entering the TNT washers. Figure 3 shows a flow diagram of the proposed magnesium sulfite purification system. The yield of purified TNT is increased by about 0.5 percent over the Sellite process because a somewhat lower pH is used during washing which produces less α-TNT complexation.

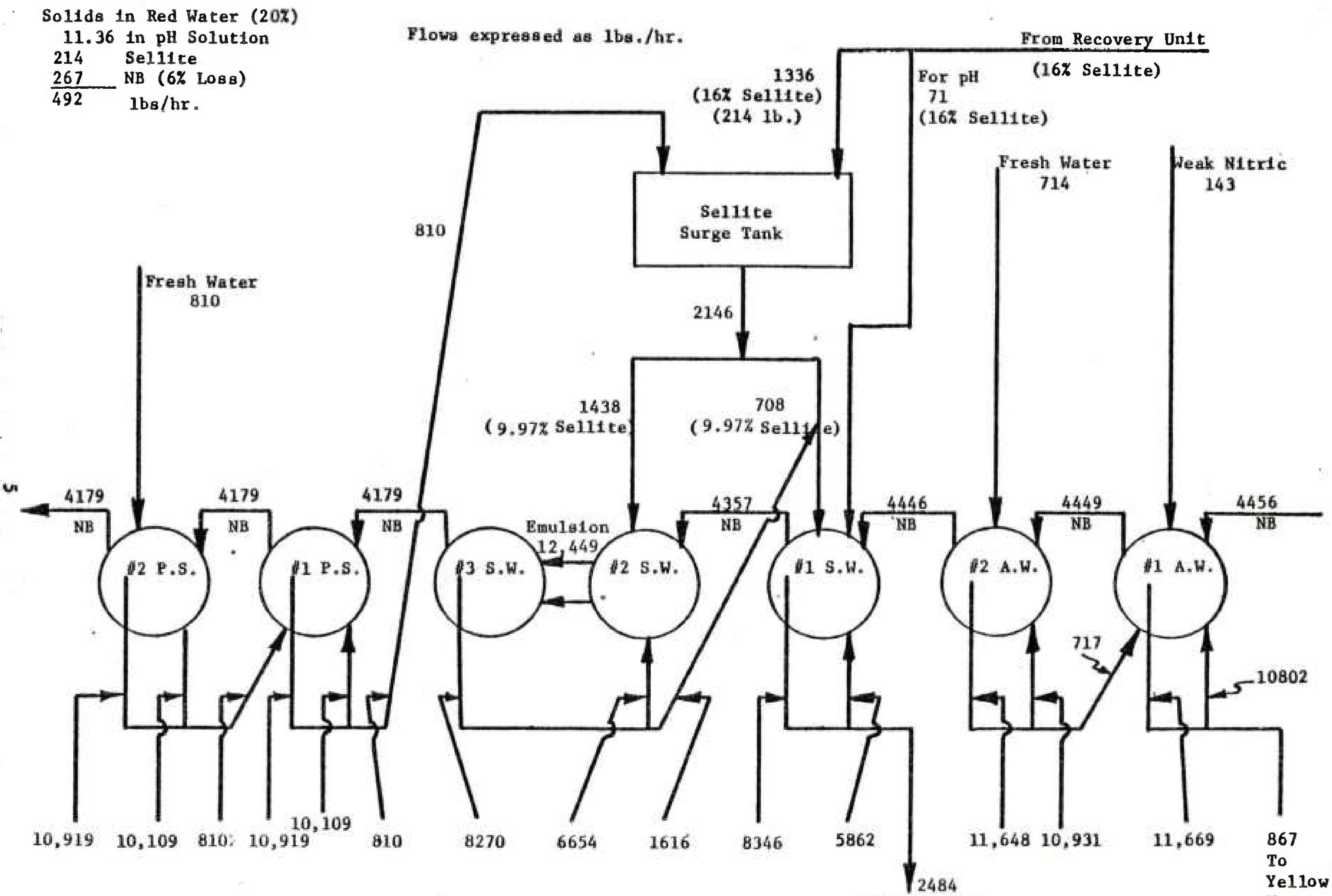


Figure 1 Sellite Purification of TNT

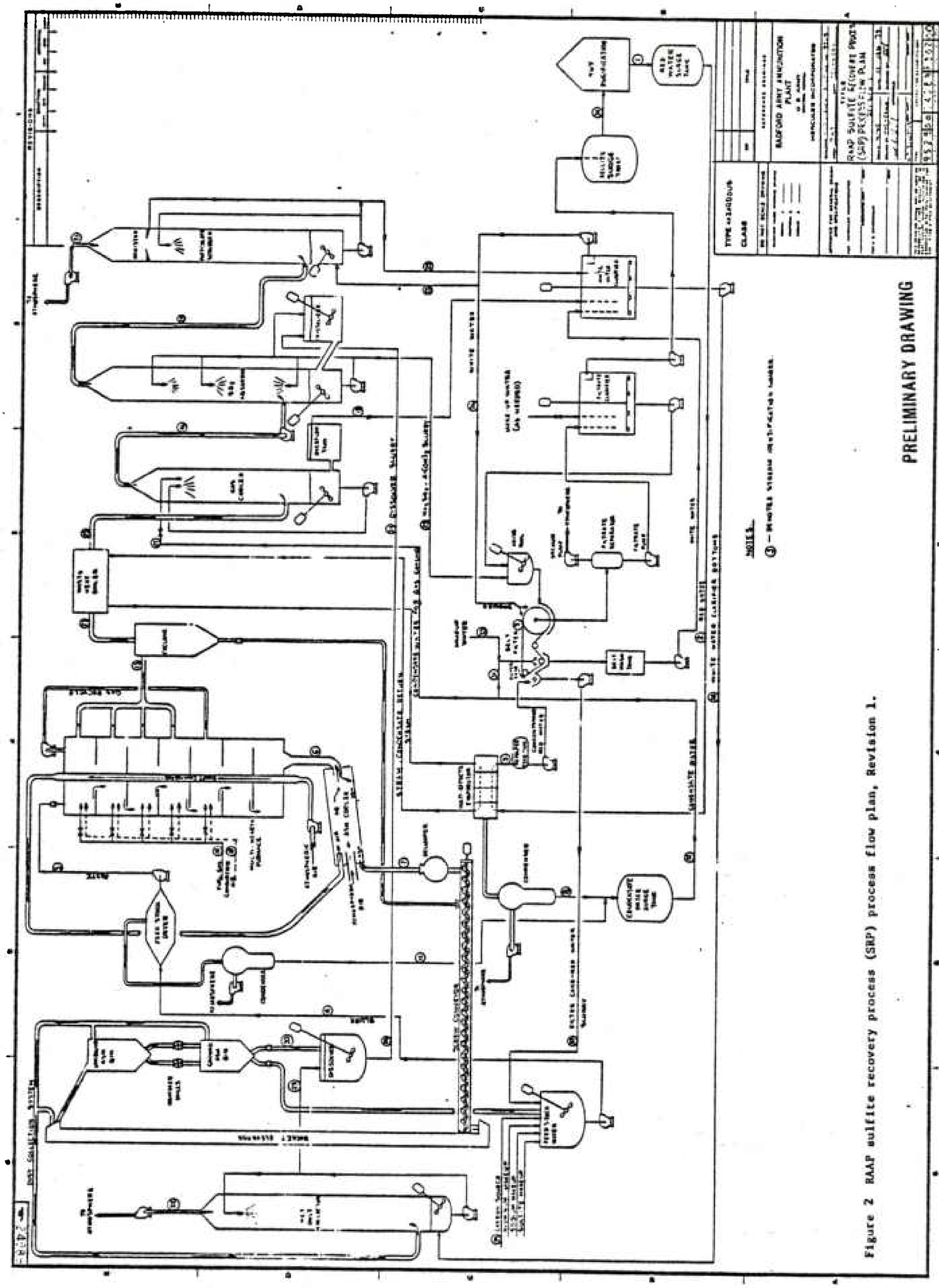


Figure 2 RAAP sulfite recovery process (SRP) process flow plan, Revision 1.

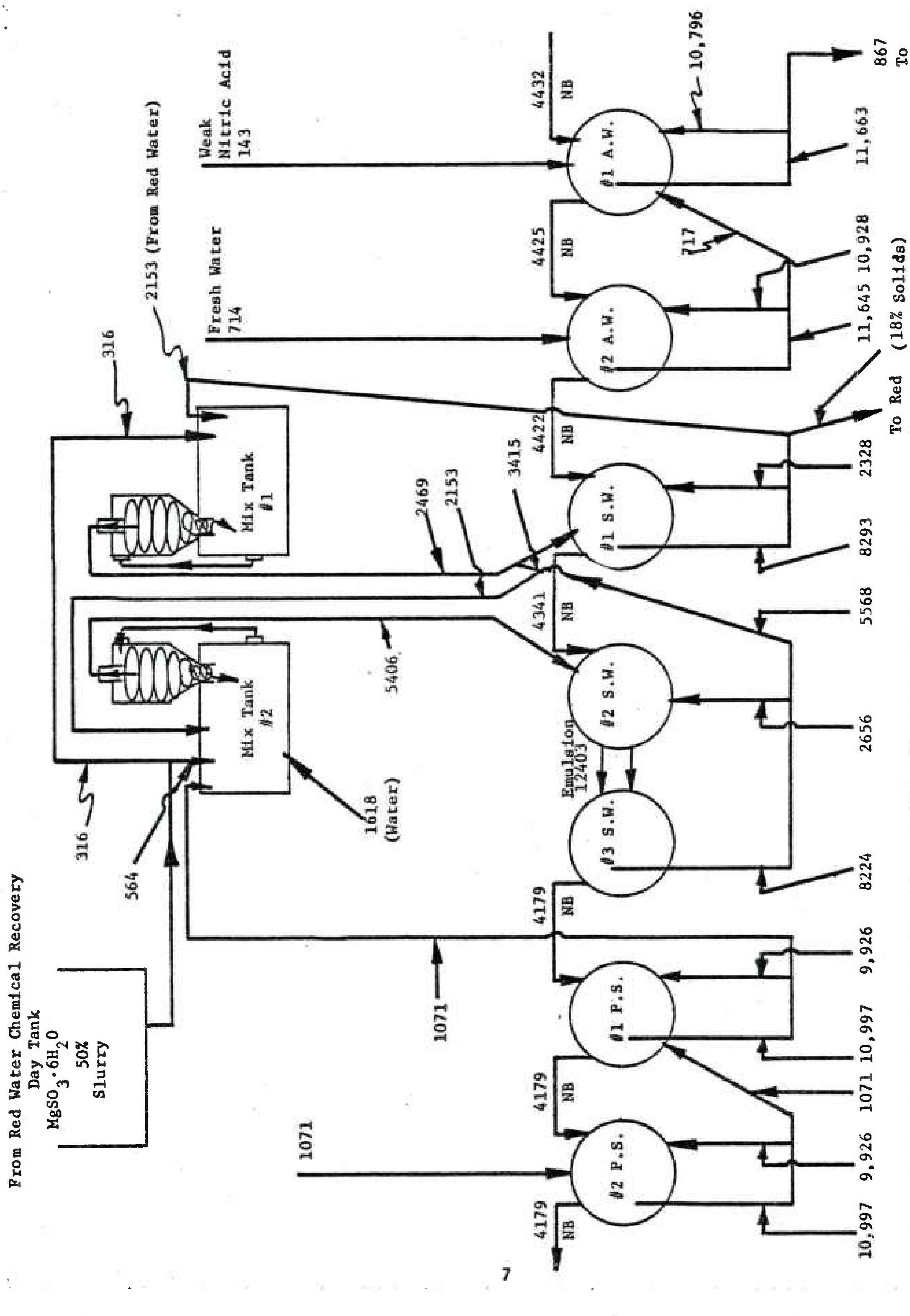


Figure 3 Magnesium Sulfite Purification of TNT Flows expressed in lbs./hr.

After TNT purification, the magnesium sulfite red water is concentrated in a multi-effect evaporator and incinerated as shown in Figure 4. One advantage of the magnesium process lies in the ease of recovering the magnesium sulfite. Incineration of the red water under reducing conditions produces magnesium oxide and sulfur dioxide which are recombined in a scrubbing tower. It should be noted that magnesium sulfate, which is present in the magnesium sulfite red water due to air oxidation of sulfite, behaves differently than sodium sulfate upon heating. The former is more easily converted to the oxide. Sodium sulfate on conventional incineration under reducing conditions forms sodium sulfide which can be converted to the sulfite by several complex chemical steps.

Nitric Acid Purification System

The nitric acid process as shown in Figure 5 purifies TNT by washing the crude TNT first with 50 percent nitric acid to remove residual sulfuric acid. The next step is the addition of 61 percent hot nitric acid for dissolution of all the crude TNT. The α-TNT is crystallized by cooling the solution carefully in stirred crystallizers and separated from the nitric acid in a continuous centrifuge. The α-TNT is then washed with water, dried, and flaked.

Figure 6 shows a diagram of the recovery process. Nitric acid is separated from the dissolved nitrobody in a falling film evaporator. The nitric acid vapor is condensed and stored for reuse. The nitrobody recovered from the nitric acid is called Isotrioil. The Isotrioil contains approximately 50 percent α-TNT and 50 percent other impurities such as dinitrotoluene (DNT), unsymmetrical TNT isomers and oxidation products. When this material is fed to a Brodie Purifier, two-thirds of the α-TNT is recovered from the Isotrioil. The Brodie Purifier as shown in Figure 7 operates similarly to fractional distillation processes except that an equilibrium exists between liquid and solid phases instead of liquid and vapor phases. The remaining Isotrioil is disposed of by incineration. Selling the Isotrioil is an alternate disposal route not treated here because marketing data does not exist. However, if this scheme was employed, facilities for washing acid from the Isotrioil and removal of red wash water by activated carbon columns would presumably be required.

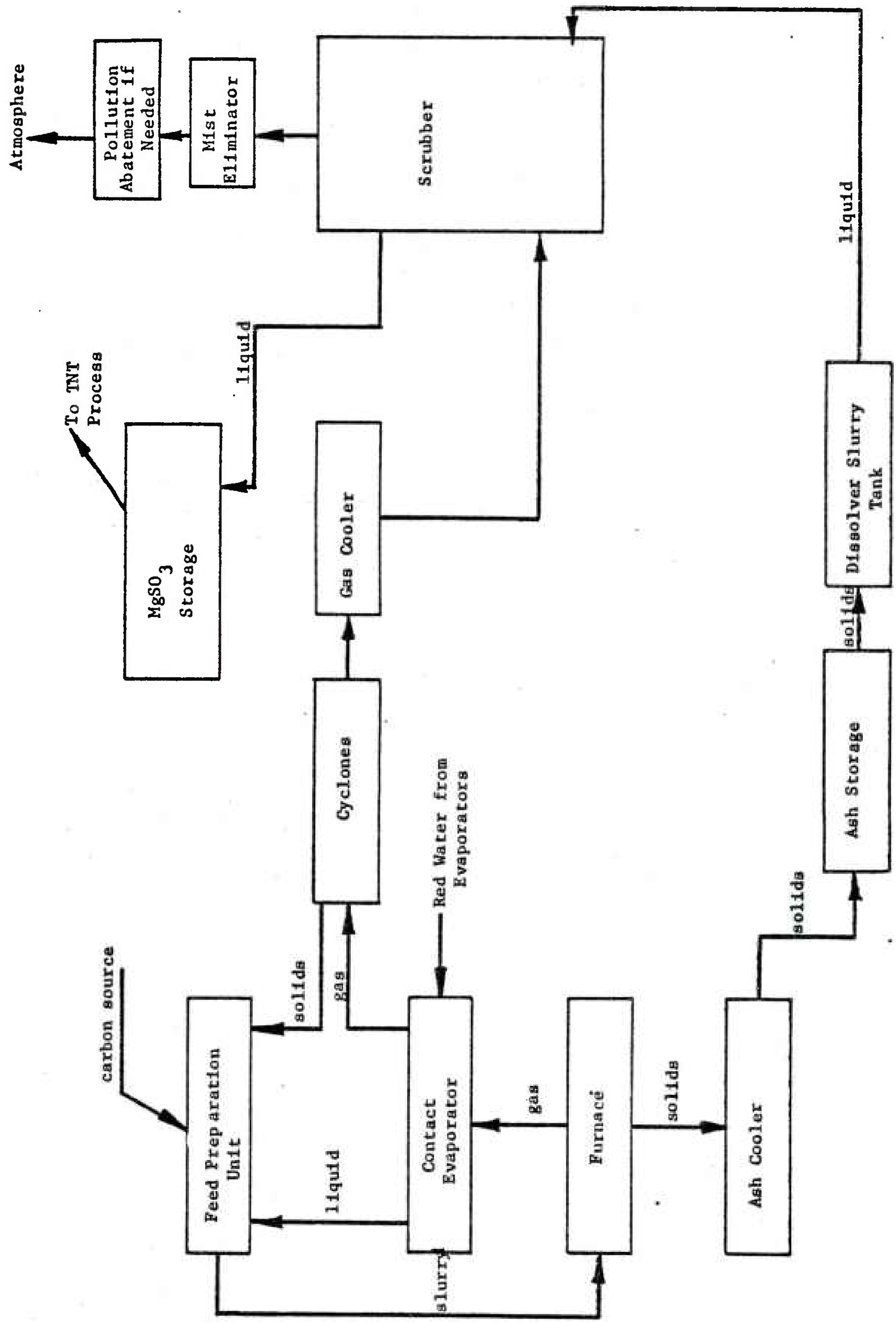


Figure 4 Magnesium Sulfite Recovery Process

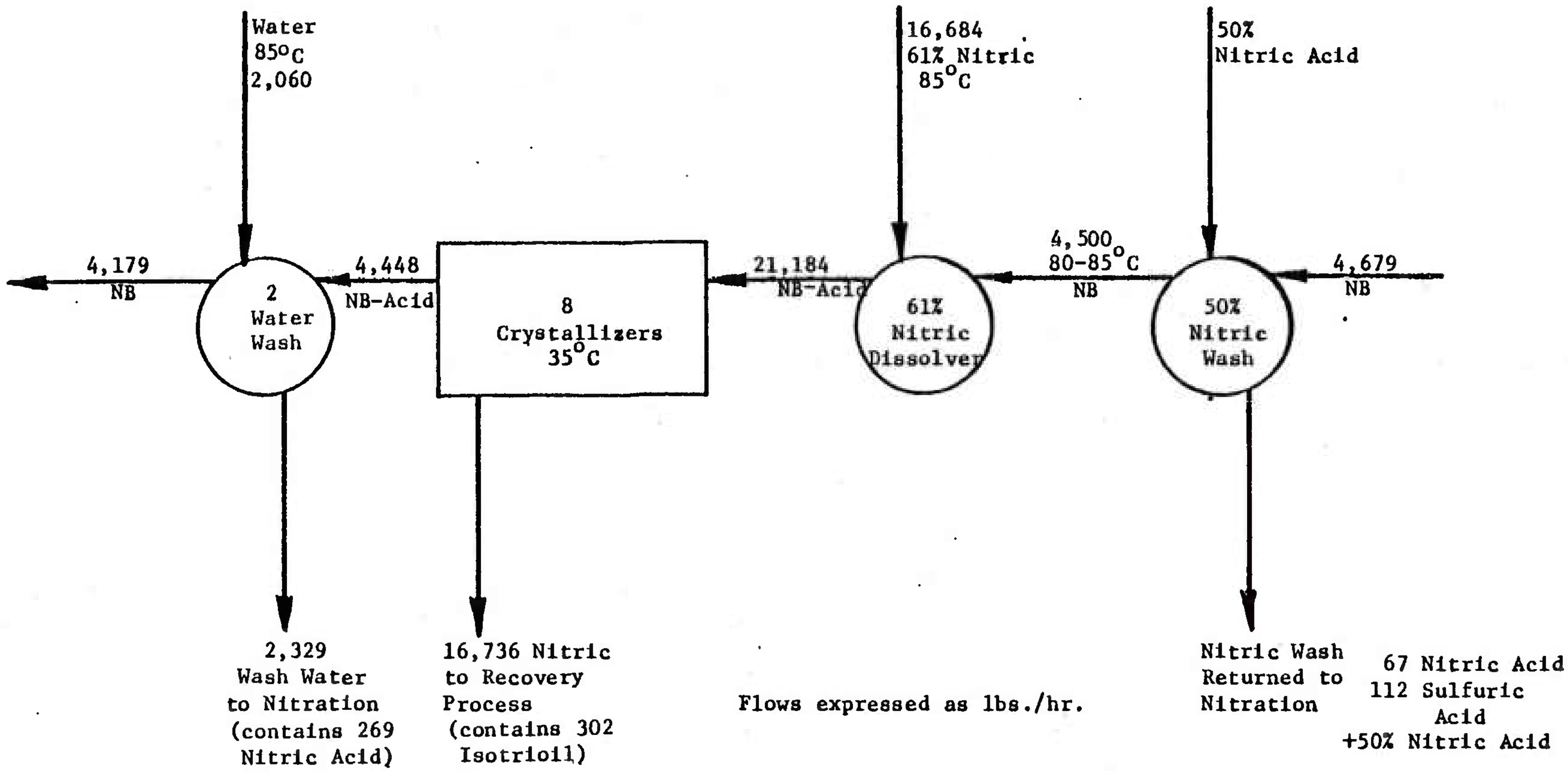


Figure 5 Nitric Acid Recrystallization-TNT Purification

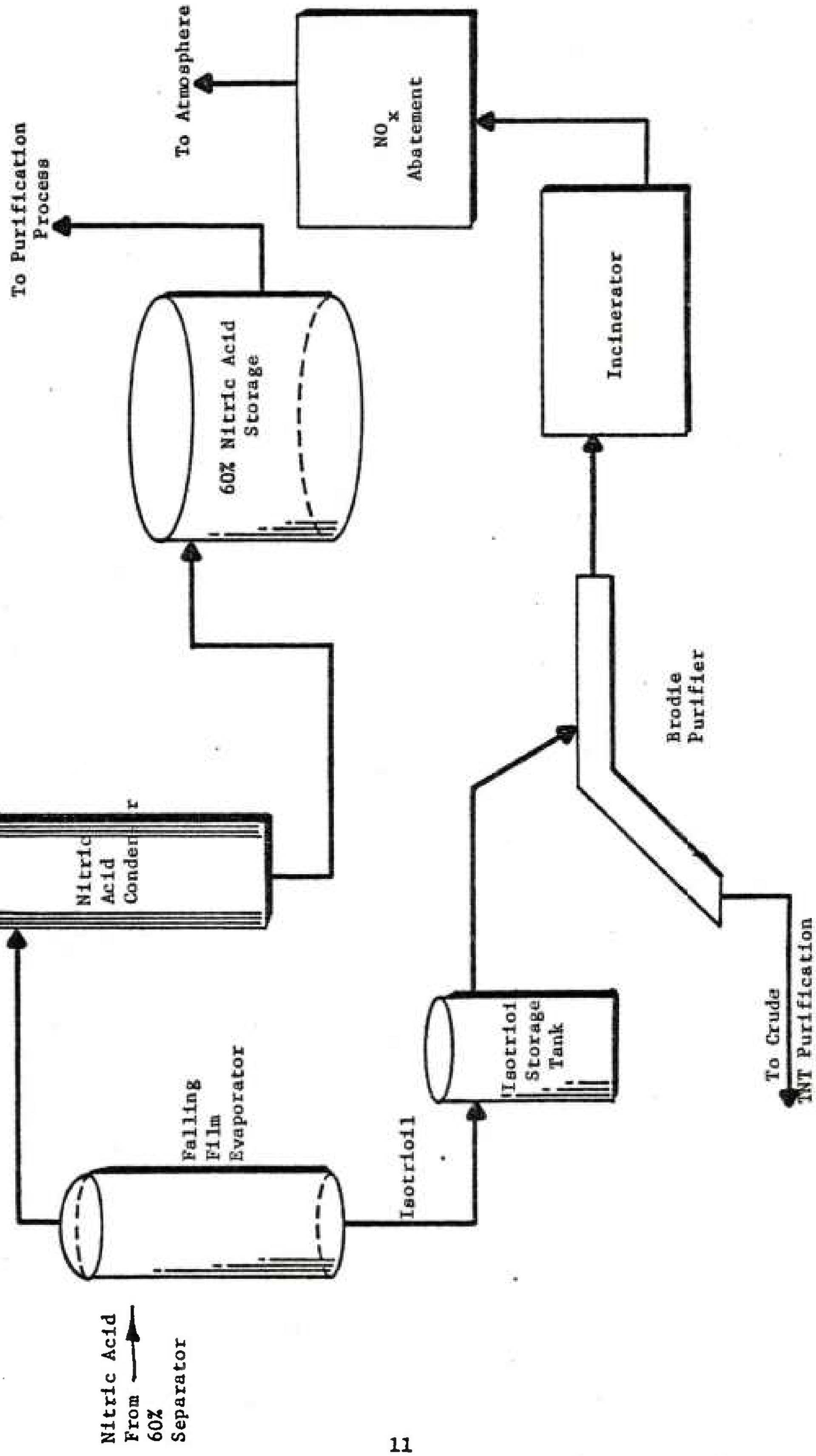


Figure 6 Nitric Acid Recovery Process

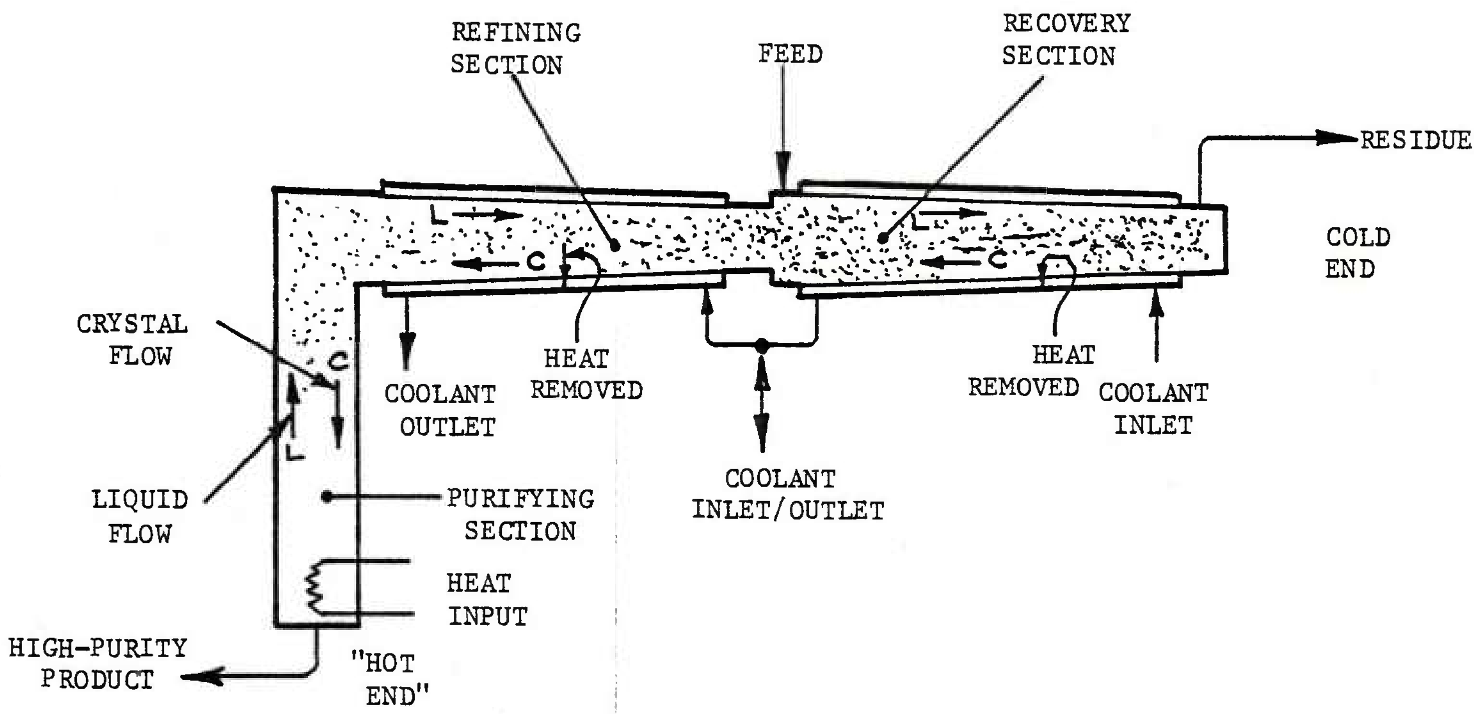


Figure 7 Typical Form of the Brodie Purifier

ECONOMIC EVALUATION OF PROCESSES

Capital and operating costs have been determined for the three purification processes as described herein. In order to achieve a suitable margin for comparison, assumptions have been developed as guidelines for the calculations and these are presented in Appendix A.

Sellite Process

Capital Costs

The capital costs for the Sellite process with chemical recovery are shown in Table 1 and detailed in Appendix B. The capital cost of $891,000 for the continuous Sellite purification section has not been included in the implemented cost for RAAP since all purification equipment has been installed. However, this should be included as a capital cost for any other plant which does not have such installed facilities. The capital cost of the continuous purification process includes dynamic separators, all necessary support equipment, buildings, piping, instrumentation and electrical supplies. The capital cost of the recovery process is $4,664,000. This figure was taken from a Sonoco SRP which is adaptable to our needs. The major equipment includes vessels, pumps, a multi-hearth kiln, tanks, piping, insulation and all equipment pertinent to the SRP unit. The total costs include buildings and site preparation, an electrical substation, and evaporators.

Overhead capital costs have been adopted for all systems or parts of systems which will need to be installed at the site. These are: 8.8 percent for Corps. of Engineers, 10 percent for contingency, 10 percent for construction fee, and 25 percent for detailed and process engineering.

Operating Costs

Table 1 also shows a summary of the individual operating costs for the continuous purification process and the SRP. This table contains all operating costs given in dollars per pound of finished TNT. The labor requirement is 17 persons for operation of the SRP on a 3-8-7 shift arrangement. The labor required for purification is the same for all three processes and therefore not included. The cost of electrical power includes the costs for operation of fans, stirrers, pumps and the hydraulic system. The cost of steam is the cost of heating the water used in the acid washer, the post Sellite washer and make-up Sellite solution. No cost is included for the steam heating of vessels and interconnecting lines, since this applied only to start-up. The heat evolved by the exothermic reaction of crude TNT and Sellite is sufficient to maintain the purification vessel at a constant temperature. Condensed steam and water from red water concentration are used to make Sellite solution.

Table 1

Summary of Sellite Purification Cost

CAPITAL COSTS

Item	Continuous Purification	Recovery	Total
Facility Cost	$891,000	$4,664,000	$5,555,000
Implementation Cost at RAAP		$4,664,000	$4,664,000

OPERATING COSTS	$/lb. TNT	$/lb. TNT	$/lb. TNT
Labor	-----------	0.009286	0.009286
Electricity	0.0004795	0.001473	0.001953
Steam	0.0008895	0.0007985	0.001685
Cooling Water	0.0003678	0.002293	0.002661
Compressed Air	-----------	0.00004066	0.00004066
Fuel	----------	0.004417	0.004417
Chemicals	0.01392	*0.01392	0.00000
Residue Loss	0.006091	---------	0.006091
Maintenance	0.001273	0.006663	0.007936
Depreciation	0.002546	0.01333	0.01588
Total With Recovery Credit	0.02557	0.02437	0.04995

*Credit due to recovered chemicals

The operating costs for fuel and compressed air apply to the SRP. The fuel cost is for both furnace start-up and concentration of the red water. When incinerated, the red water solids supply only a limited amount of heat energy. The majority of the heat energy must be supplied from an outside source.

The total operating cost for the Sellite purification and recovery operation is calculated to be 6.387 cents per pound of finished TNT. A credit for recovery of chemicals decreases the operating cost to 4.995 cents per pound of finished TNT. The total capital cost as previously stated is $4,664,000 which is essentially the cost for implementing the SRP at RAAP.

Magnesium Sulfite Process

Capital Costs

The capital costs for both the purification and the chemical recovery sections of the magnesium sulfite process are shown at the top of Table 2, and also are detailed in Appendix C. The capital costs for the purification section of the magnesium sulfite process reflect an additional day storage tank, hydrocyclones, pump, stirrer, and tank. The additional cost for implementing this purification section is $21,000. The capital cost of the magnesium sulfite recovery system is similar to the Sellite system except that the belt filter, tank, and two clarifiers are not required. The cost of the magnesium sulfite recovery system is, therefore, $328,000 less than the Sellite recovery system. The capital cost of the chemical recovery unit for the magnesium sulfite system is $4,336,000. RAAP's implementation cost of the total magnesium sulfite system is $4,357,000 since only $21,000 is required to convert from the present purification system to the magnesium system.

Operating Costs

The operating cost of the magnesium sulfite purification system is also shown in Table 2. No additional labor is required for the operation of the purification system. Seventeen persons are required to operate the recovery section. The electrical power is for operation of pumps, stirrers, separators, and fans. The cost of steam is the cost for heating all the water used in the system. Steam used to preheat the vessels and lines is not considered since this amount is negligible. The heat needed to maintain the vessel temperatures originates from the heat of reaction of magnesium sulfite with crude TNT. The steam cost figure for the recovery system is the steam needed for concentrating the red water to an 80 percent solids content before it enters the kiln. Cooling water costs comprise all the water needed for cooling both the purification vessels and the recovery system. The cost figure for the chemicals is the cost of magnesium oxide, sulfur, and the water used in the purification phase. The chemical recovery section is

Table 2

Summary of Magnesium Sulfite Purification Cost

CAPITAL COSTS Item	Continuous Purification	Magnesium Sulfite Recovery	Total
Facility Cost	$912,000	$4,336,000	$5,248,000
Implementation Cost at RAAP	$ 21,000	$4,336,000	$4,357,000
OPERATING COSTS	$/lb. TNT	$/lb. TNT	$/lb. TNT
Labor	----------	0.009286	0.009286
Electricity	0.0004892	0.001429	0.001918
Steam	0.001073	0.0007958	0.001869
Cooling Water	0.0003678	0.002153	0.002521
Compressed Air	----------	0.00004066	0.00004066
Fuel	----------	0.005063	0.005063
Chemicals	0.02252	*0.02252	0.00000
Residue Loss	0.004040	----------	0.004040
Maintenance	0.001303	0.006194	0.007497
Depreciation	0.002606	0.01239	0.01500
Chemical Recovery Credit	----------	*0.02252	0.02252
Total Cost including credit for recovery	0.03240	0.01483	0.04723

*Credit for recovered chemicals

assumed to recover 100 percent of these chemicals since there is insufficient information to assess actual percentage of chemical recovery. Therefore, the entire cost of the chemicals is credited in the chemical recovery section. The residue loss figure (one percent) is the cost of the α-TNT lost in the magnesium sulfite red water. The fuel cost is for fuel consumed in the chemical recovery unit. Fuel is used for kiln start-up and also for the concentration of the red water. The maintenance of the system is computed as five percent of the capital cost. The depreciation cost is figured as a 10-year straight line depreciation on the capital cost. The total operating cost for this system including a credit for the recovery of chemicals is calculated to be 4.72 cents per pound of finished TNT.

Nitric Acid Recrystallization

Capital Costs

This method of TNT purification employs a purification stage, a nitric acid recovery stage, an α-TNT recovery stage, and an incineration stage to destroy nitrobody wastes. The capital cost is shown at the top of the summary sheet on Table 3 and is detailed in Appendix D. The total capital cost of the purification stage and the nitric recovery stage was taken from a study entitled "Engineering Study of the Adoption of Continuous Nitric Acid Purification to Continuous TNT Production Facilities", (Leonard Process Co., Inc.) and escalated to 1978 levels. The capital cost of the purification system is $2,404,000. This includes all the equipment, foundations, structures, buildings, barricades, piping, instruments, electrical equipment and the overhead fees mentioned earlier for each phase of the process to be implemented. The nitric acid recovery capital cost is $749,000 per line. Since the other recovery systems are calculated for a two line capacity, the final recovery system cost is $1,498,000. This cost includes all equipment, preparation, and installation of the equipment. The Brodie Purifier's capital cost is $621,000 for a unit sized to handle two TNT lines. This cost includes the actual purifier unit, site preparation, tanks, and all piping needed. The capital cost of the incineration process is $3,802,000. The cost is derived from data on the RAAP explosive and propellant incinerator which meets all applicable environmental and safety regulations. This figure is included since the present waste propellant incinerator at RAAP does not have the capacity to support two TNT lines. The implementation capital cost for the entire nitric acid purification system at RAAP is $8,325,000. The capital costs may be reduced significantly if the Istrioil could be commercially marketed without removal of residual acid. Most probably the acid would have to be removed before sale. Acid neutralization would require facilities for treatment of the red water which would be produced.

Operating Costs

A summary of the operating cost in dollars per pound of finished TNT is also given in Table 3. The only labor required is one-half person per shift for the Brodie Purifier and three persons per shift for the incinerator. Electrical power is required in all four sections for motors, pumps, fans and stirrers. The steam cost includes heating all water used in each system as well as the steam used for evaporation and heat. The cooling water includes the cost of all the water used for cooling. The process water cost is for the water actually entering the system.

Table 3

Summary of Leonard Nitric Acid Purification

CAPITAL COSTS	Cont. Purif.	HNO_3 Rec.	Brodie Rec.	Incinerator	Total
Implementation Cost at RAAP	$2,404,000	$1,498,000	$621,000	$3,802,000	$8,325,000

OPERATING COSTS	$/lb. TNT	$/lb. TNT	$/lb. TNT	$/lb.TNT	$/lb. TNT
Labor	--------	---------	0.0008088	0.004853	0.005662
Electricity	0.0004196	0.00004879	0.00003924	0.0005855	0.001093
Steam	0.003237	0.008580	0.00004290	---------	0.01186
Cooling Water	0.0005616	0.001872	0.00002877	0.00001310	0.002475
Process Water	0.0002100	---------	0.000008034	0.00004680	0.0002648
Fuel (oil/gas)	--------	---------	----------	0.003118	0.003118
Nitric Acid Loss	0.007080	0.0001316	----------	---------	0.007212
TNT Loss	0.01420	--------	0.009696*	---------	0.004504
Maintenance	0.003434	0.001070	0.0008871	0.005431	0.01082
Decpreciation	0.006869	0.002140	0.001774	0.01086	0.02164
Total wich Credit	0.03601	0.01384	0.006107*	0.02491	0.06865

*Recovery Credit

(The figure used in the nitric acid loss is the cost of the nitric acid not recovered either in purification or recovery sections.) In the Brodie Purifier process, a credit is given for approximately two-thirds of the α-TNT in the Isotrioil. The fuel cost is based on quantities of fuel necessary to maintain the operation of the incinerator. The maintenance cost is five percent of the capital cost. The depreciation is calculated as a 10-year straight line depreciation of the capital cost of each phase of the process. The total operating cost for the nitric acid system is calcualted to be 6.865 cents per pound of finished TNT.

CONCLUSIONS

The estimated comparative investments for the three purification processes are shown below in thousands of dollars: The numbers represent the implementation cost at RAAP. The estimated operating costs for the three processes are shown in dollars per pound of finished TNT:

	Sellite	Magnesium Sulfite	Nitric Acid
Facility Costs (thousands)	\$4,664	\$4,357	\$8,325
Operating Cost (\$/lb. TNT)	0.04995	0.04723	0.06865

There is an indicated savings of \$0.00272 per pound of TNT for the magnesium sulfite purification system as compared to the Sellite purification system. A cash savings of about \$95,200 per year would therefore occur from the production of 35,000,000 pounds per year of TNT.

These cost studies give credit for a 100 percent recovery and reuse of all chemicals. The actual recovery efficiencies could not be determined but will be somewhat less than 100 percent. The economic advantage listed above for the magnesium sulfite process may not be totally valid since make-up chemicals are more expensive for the magnesium process as compared to the Sellite process.

From a technical standpoint, all three processes appear feasible. The Sellite purification system is presently used for TNT manufacture. Recovery of Sellite from the red water is being investigated on a pilot scale using Sonoco technology.

Laboratory studies indicate that magnesium sulfite could be a suitable substitute for Sellite in the TNT purification process and the resulting by-product, magnesium sulfate, can be recycled to the sulfite for purification reuse. This method of TNT purification has not yet been proven on a production scale. Inherent in its design is a requirement for more process control than in the Sellite process.

The nitric acid purification process is practiced commercially but not in the Leonard configuration. The use of the Brodie purifier to recover α-TNT from the Isotrioil has not been demonstrated. The Isotrioil after α-TNT removal was considered to be incinerated in this study. Alternate disposal techniques such as chemical alteration for subsequent use or perhaps sale of the Isotrioil exist. Adequate technical feasibility and cost data are not available to assess these approaches.

RECOMMENDATIONS

The comparative cost data indicates that the magnesium sulfite process is economically competitive with the Sellite process. However, a full assessment of the TNT produced from the laboratory purification runs has not been completed at this time nor has an evaluation of a full-scale purification or recovery process been demonstrated.

The recovery of sodium sulfite from presently produced red water has been demonstrated conceptually by piloting integral portions of the Sonoco SRP process. Therefore, it is recommended that only limited pilot plant efforts be considered on the magnesium sulfite process since evaluation of scaled up magnesium sulfite systems would be cost prohibitive and occur at a time the Sellite recovery process was well underway.

The nitric acid process would be more economical if a commercial market or other means of utilization could be established for Isotrioil. It is recommended that some consideration be given to these alternatives.

Appendix A

Assumptions for the Comparative Cost Study

The comparative cost study was based on the following assumptions:

1. All capital investments in the purification phase of each system are calculated per TNT line.

2. All capital investments on the recovery phase of each system are calculated to process wastes from two TNT lines.

3. All operating costs are based on a 50-ton per day production line and are given as dollars per pound of finished TNT.

4. Four percent loss of the crude TNT due to the unsymmetrical isomers will occur in each purification process.

5. Residue loss is assumed to be only the α-TNT lost. This amounts to 1.5 percent in the Sellite system, 1.0 percent in the magnesium sulfite system and 3.25 percent in the nitric acid system.

6. Both the Sellite and the magnesium sulfite systems are assumed to recover one hundred percent of the chemicals involved. No material or equipment costs are included for addition of chemicals lost from process inefficiencies.

7. No license fees are included in any of the systems.

8. The costs do not include utility services, safety devices, or any other requirements to meet applicable standards.

9. Approximately one-third of the nitrobodies are reclaimed from the nitric acid purification system via the Brodie Purifier. The remaining nitrobodies would be incinerated.

10. The nitric acid system is the only system which contains a capital cost for incineration of nitrobodies or other wastes.

11. The Sonoco chemical recovery unit costed in this report is the smallest unit for which cost figures are available. It will actually handle four Sellite lines.

12. The chemical recovery units in both the Sellite and magnesium sulfite processes have a deficiency in energy which is required to evaporate the water. This energy will be supplied by natural gas.

13. The actual implementation cost of the purification systems at RAAP for Sellite and magnesium sulfite are each system's cost minus the cost for Sellite purification. This is because RAAP already has the facilities for the Sellite purification mentioned in this estimate.

14. The operating cost of each system is given including the credit for the recovered chemicals.

15. The amount of nitric acid lost in the Sellite and magnesium sulfite systems is considered negligible and not included in process cost estimates.

16. The depreciation of each system is accepted as a 10-year straight line depreciation for all three processes.

17. The maintenance of each system is accepted as five percent of the initial capital investment.

18. All nitrobodies leaving the purification line are considered soluble in the red water and will be destroyed in the chemical recovery's kiln for both the Sellite and the magnesium sulfite systems.

19. All capital costs in the three processes with the exception of the purification sections of the Sellite and magnesium sulfite, include an additional cost for Corps. of Engineers (8.8 percent), contingency (10 percent), construction fee (10 percent) and detailed and process engineering (25 percent).

20. No additional labor is required for any of the purification phases of each system. The operators required for the nitration process will also control purification.

21. All operational costs are based on current prices of the involved items or goods at RAAP.

22. The magnesium sulfite chemical recovery capital and operating costs are obtained by making a direct comparison with the Sonoco chemical recovery unit.

23. The nitrobody value is assumed to be $0.40 per pound. The current market price is actually much higher.

24. Heat of vaporization for water is $2,338,391 joules per kilogram or 1006 Btu per pound.

25. No overhead or fringe benefits are included.

Appendix B

Cost Data for the Sellite Purification System

1. Capital Costs [1]

   a. Purification

Building and Services	\$228,000
Process Equipment	435,000[2]
Process Piping	110,000
Instrumentation	56,000
Electrical Instrument, etc.	62,000
	\$891,000[3]

[1] Capital cost figures were taken from Leonard Process Co., Inc. Report dated October 19, 1970 entitled, "Engineering Study of the Adoption of Continuous Nitric Acid Purification to Continuous TNT Production Facilities" (CIL Process) Prices escalated from 1970 to 1978.

[2] Includes dynamic separators.

[3] This system has been implemented here at RAAP, therefore, this cost can be deducted from the total capital cost when implementing this Sellite system at RAAP.

b. Recovery[1]

Major Equipment			$1,830,000
Buildings and Site Preparation[2]			256,000
Electrical[3]			132,000
Evaporators			738,000
		Sub Total	$2,956,000
Corps. of Engineers	8.8 percent		260,000
Contingency	10 percent		322,000
Construction fee	10 percent		322,000
Detailed and Process Engineering	25 percent		804,000
		Sub Total	$1,708,000
		Total	$4,664,000

[1]Costs are taken from Sonoco's reports entitled, "Experience with a new Sulfite Recovery Process", and "Sonoco Sulfite Recovery Process Costs Data". These costs have been escalated to 1978 figures (factor of 1.255). The operating cost of the recovery system is included in return for the credit of 100 percent recovery of the Sellite.

[2]Includes miscellaneous equipment, piping, insulation, and painting.

[3]Includes instruments, wiring, and substation.

2. Operating Costs

a. Purification

Electrical Power	HP
Yellow Water Tank Stirrer	0.25
Sellite Washer drive #2 Washer	1.00
Post Sellite Stirrer	0.25
Fume Recovery Fans	4.00
Weak Nitric Pump	0.15
Dissolver #1 feeder	0.33
Dissolver #10 Mixer	0.75
Ph control Dissolver mixer	0.75
Ph control Dissolver feeder	0.33
	7.81

$$\frac{7.81\text{ H.P./Hr.} \times 24\text{ Hr./day} \times .7457\text{ KWH/HP} \times \$0.02725\text{/KWH}}{100{,}000\text{ lb. TNT/day}} = \$0.00003809\text{/lb. TNT}$$

Hydraulic Motors	HP
#1 Acid Washer	14
#2 Acid Washer	14
#1 Sellite Washer	14
#2 Sellite Washer	2.5
#3 Sellite Washer	14
#1 Post Sellite Washer	14
#2 Post Sellite Washer	14
Yellow Water Pump	2
TNT Pump Tank	2
	90.5

$$\frac{90.5\text{ HP/HR} \times 24\text{ HR/day} \times .7457\text{ KWH/HP} \times \$0.02725\text{/KWH}}{100{,}000\text{ lb. TNT/day}} = \$0.0004414\text{/lb. TNT}$$

Sub Total $0.0004795/1b. TNT

Steam

Hot water requirements

#2 acid washer	714 lb/hr
#2 Post Sellite washer	1071 lb/hr
16 percent Sellite solution	59 lb/hr
	1844 lb/hr

Power house - 7.5 lb of steam per lb. of coal
Steam to TNT Plant contains 1268 BTU per lb.
1006 BTU required per lb. of water to attain 80°C
Coal - $38.00 per ton or $0.019 per lb.

$$\frac{1844 \text{ lb. water/hr} \times 24 \text{ hr/day} \times 1006 \text{ BTU/lb } H_2O \times \$0.019\text{/lb coal}}{100{,}000 \text{ lb TNT/day} \times 1268 \text{ BTU/lb steam} \times 7.5 \text{ lb steam/lb coal}} = \$0.0008895\text{/lb. TNT}$$

Steam is used initially with each start-up to heat each purification washer and interconnecting line to temperature. This amount of steam was considered negligible and also fairly even in all three purification systems and therefore was not used in these costs.

Cooling Water

786 gal/min of cooling water is used to cool the entire manufacturing process. Only 25 percent of this is used in the purification phase.

$$\frac{786 \text{ gal/min} \times 60 \text{ Min/for} \times 24 \text{ hr/day} \times .25 \text{ percent} \times \$0.00013\text{/gal } H_2O}{100{,}000 \text{ lb TNT/day}} = \$0.0003678\text{/lb. TNT}$$

Depreciation - 10-year straight line depreciation investment:

Building and Services	$228,000
Process Equipment	435,000
Process Piping	110,000
Instrument	56,000
Electrical Instrument, etc.	62,000
	$891,000

$$\frac{\$891{,}000/\text{capital investment}}{\text{10-yr/capital investment} \times 350\ \text{days/yr} \times 100{,}000\ \text{lb. TNT/day}} = \$0.002546/\text{lb. TNT}$$

Chemicals

Sellite - .0842757 lb. Sellite required to purify each lb. of TNT.

.0842757 lb. Sellite/lb. TNT x $0.1650/lb. Sellite - $0.01391/lb. TNT

Water - used in the process

1071 lb/hr (134 gal/hr)in #2 Post Sellite Washer
59 lb/hr (7.35 gal/hr) in #1 Sellite Washer
714 lb/hr (89 gal/hr)in #2 Acid Washer

$$\frac{230\ \text{gal/hr} \times 24\ \text{hr/day} \times \$0.00013/\text{gal}}{100{,}000\ \text{lb. TNT/day}} - \$0.000007176/\text{lb. TNT}$$

Sub Total $0.01392/lb. TNT

100 percent of chemicals recovered and credited under Recovery Section.

Residue Loss @ $0.40/lb.

Sellite Purification system has a 1.5 percent α-TNT loss
50 ton per day rate equals 101,523 lb./day of crude TNT

$$\frac{101{,}523\ \text{lb. crude TNT/day} \times .015\ \text{percent} \times \$0.40/\text{lb crude TNT}}{100{,}000\ \text{lb. TNT/day}} = \$0.006091/\text{lb. TNT}$$

Maintenance

5 percent of the capital investment is used for maintenance

$$\frac{\$891{,}000 \times .05\ \%/\text{yr.}}{\times\ 100{,}000\ \text{lb TNT/day}/350\ \text{days/yr}} = \$0.001273/\text{lb. TNT}$$

TOTAL $0.02557/lb. TNT

b. Recovery

Labor — The recovery section requires 17 operators for a total of \$380,479/year minus \$55,479.61 for overhead and fringe benefits

$/lb. TNT

$$\frac{\$325{,}000.00/\text{year}}{350\ \text{day/year} \times 100{,}000\ \text{lb/day}} = 0.009286$$

Electricity
$$\frac{\$51{,}540.00/\text{year}}{350\ \text{day/year} \times 100{,}000\ \text{lb/day}} = 0.001473$$

Steam
$$\frac{\$27{,}853.47/\text{year}}{350/\text{day/year} \times 100{,}000\ \text{lb/day}} = 0.0007958$$

Cooling Water
$$\frac{1225\ \text{gal/min} \times 60\ \text{min/hr} \times 24\ \text{hr/day} \times \$0.00013/\text{gal}}{100{,}000\ \text{lb/day}} = 0.002293$$

*Fuel (Start-up)
$$\frac{2167\ \text{cu. ft./hr} \times 24\ \text{hr/day} \times \$0.00193/\text{cu. ft.}}{100{,}000\ \text{lb TNT/day}} = 0.001004$$

Residue loss - Considered previously in Purification

Maintenance
$$\frac{\$4{,}664{,}000 \times .05\ \text{percent}}{350\ \text{day/year} \times 100{,}000\ \text{lb/day}} = 0.00663$$

Depreciation
$$\frac{\$4{,}664{,}000}{350\ \text{day/year} \times 10\ \text{year} \times 100{,}000\ \text{lb./day}} = 0.01333$$

System BTU deficiency

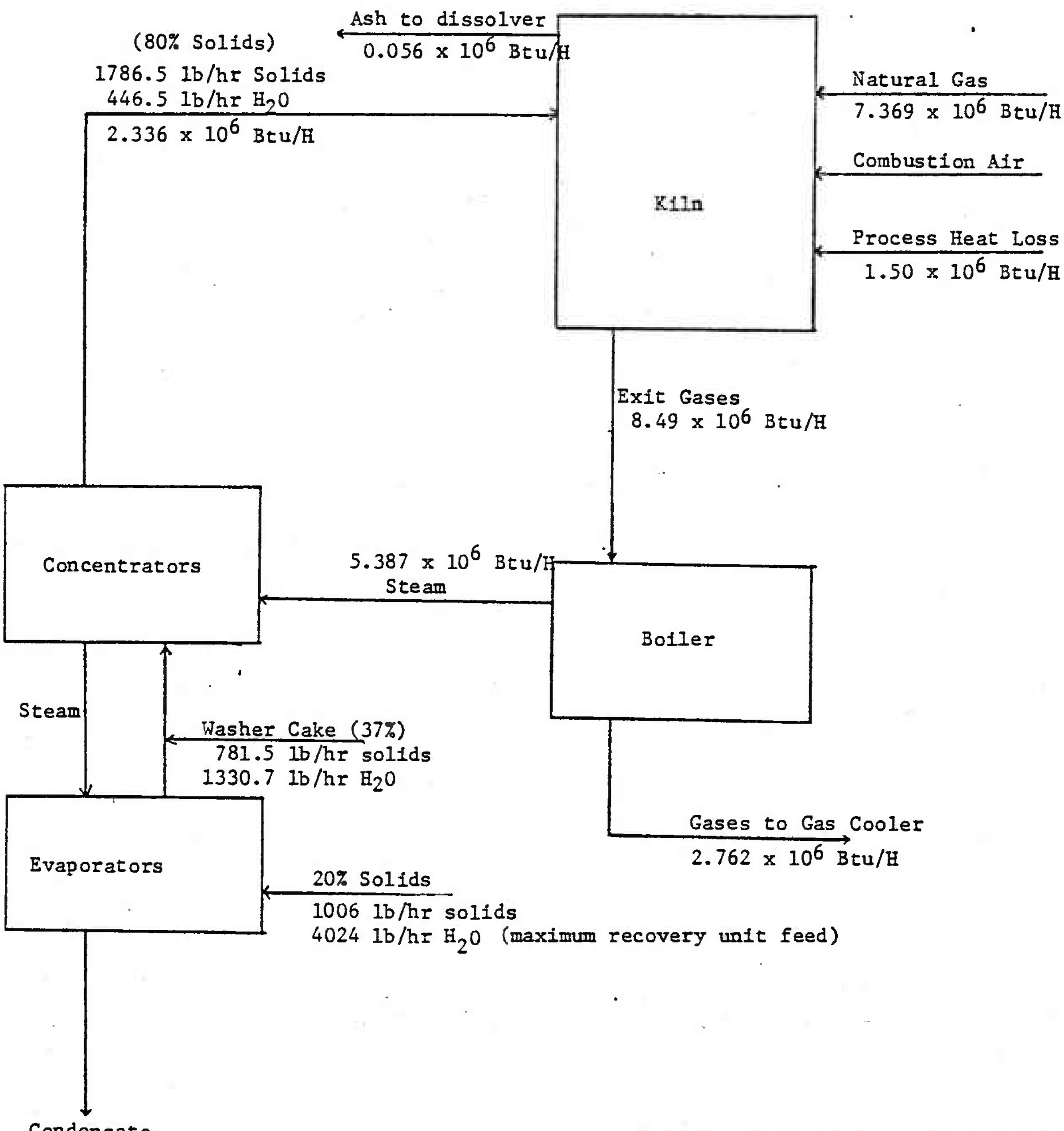
$$\frac{7{,}368{,}896.2\ \text{BTU/hr} \times 24\ \text{hr/day} \times \$0.00193/\ \text{cu. ft.}}{1000\ \text{BTU/cu. ft.} \times 100{,}000\ \text{lb TNT/day}} = 0.003413$$

Sub Total 0.004417

* See Figure B-1 for energy efficiency.

Compressed air	$\dfrac{\$1,423.17/\text{year}}{350 \text{ day/year} \times 100,000 \text{ lb. TNT/day}}$	=	0.00004066
Chemicals	(100 percent recovery)		
	\$0.01392/lb. TNT x 1.00	=	0.01392
	Operating cost including credit for recovery	=	0.02437

Energy Efficiency in the Sellita Recovery Process[1]



Heat available from solids
1006 lb. solids/hr
x2322 Btu/lb
2,335,932 Btu/hr

+2,762,000 Btu gas cooler
+ 56,000 Btu ash
+1,500,000 Heat Loss
+5,386,828.2 Needed to Evap. H_2O
-2,335,932 Btu available from solids
7,368,896.2 Btu needed

Heat energy needed to evaporate H_2O
4024 lb H_2O/hr
+1330.7 lb H_2O/hr
5354.7 lb H_2O/hr total
x1006 Btu/lb
5,386,828.2 Btu/H required to evaporate H_2O

$$\frac{7,368,896.2 \text{ Btu/hr} \times 24 \text{ hr/day} \times \$0.00193/\text{cu.ft.}}{1000 \text{ Btu/cu. ft.} \times 100,000 \text{ lb/TNT day}} = 0.003413 \text{ /lb. TNT}$$

[1]Capacity for 2 TNT Lines

Figure B-1

Appendix C
Cost Data for the Magnesium Sulfite Purification System

1. Capital Costs[1]

   a. Purification

Building and Services		\$228,000
Process Equipment		456,000[2]
Process Piping		110,000
Instrumentation		56,000
Electrical Instrument, etc.		62,000
	Total	\$912,000[3]

[1]Capital cost figures based on Report from Leonard Process Co., Inc. dated October 19, 1970 entitled "Engineering Study of the Adoption of Continuous Nitric Acid Purification to Continuous TNT Production Facilities". (CIL Process). Prices escalated from 1970 to 1978.

[2]Includes dynamic separators, fortification tank, hydrocyclones, pump and day tank.

[3]For implementation cost at RAAP, due to Sellite equipment already installed, deduct \$891,000 leaving \$21,000.

b. Recovery[1]

Item			Cost in dollars
Major Equipment			1,622,000
Buildings and Site Preparation[2]			256,000
Electrical			132,000
Evaporators			738,000
		Sub Total	2,748,000
Corps. of Engineers	8.8 percent		242,000
Contingency	10 percent		299,000
Construction fee	10 percent		299,000
Detailed and Process Engineering, 25 percent			748,000
		Sub Total	1,588,000
		Total	$4,336,000

[1]Cost of both the equipment and the operating are based on costs from a similar process in Sonoco's report entitled, "Experience with a new Sulfite Recovery Process," and "Sonoco Sulfite Recovery Process Cost Data." These costs have been escalated to 1978 figures.

[2]Includes miscellaneous equipment, piping, insulation, and painting.

[3]Includes instruments, wiring and substation.

2. Operating Costs

a. Purification

Electrical Power

	HP
Yellow Water Tank Stirrer	.25
Sellite Washer Drive #2	1.00
Post Sellite Stirrer	.25
Fume Recovery Fans	4.00
Weak Nitric Acid Pump	0.15
Dissolver #1 Pump	0.33
Dissolver #1 Stirrer	0.75
Dissolver #2 Pump	0.33
Dissolver #2 Stirrer	0.75
Day Tank Stirrer	1.00
Day Tank Pump	1.00
	9.81

$$\frac{9.81 \text{ HP/hr} \times 24 \text{ hr/day} \times .7457 \times \$0.02725/\text{KWH}}{100{,}000 \text{ lb TNT/day}} = \$0.00004784/\text{lb. TNT}$$

Hydraulic Motors

	HP
#1 Acid Washer	14
#2 Acid Washer	14
#1 Sellite Washer	14
#2 Sellite Washer	2.5
#2 Sellite Washer	14
#1 Post Sellite Washer	14
#2 Post Sellite Washer	14
Yellow Water Pump	2
TNT Pump Tank	2
	90.5

$$\frac{90.5 \text{ HP/hr} \times 24 \text{ hr/day} \times .7457 \times \$0.02725/\text{KWH}}{100{,}000 \text{ lb TNT/day}} = \$0.0004414/\text{lb. TNT}$$

Sub Total $0.0004892/lb. TNT

Steam (to heat water used in Process)

#2 Acid Washer	714 lb/hr
#2 Post Sellite Washer	1071 lb/hr
Day Tank	440 lb/hr
	2225 lb/hr

Power house - 7.5 lb steam per lb. coal
Steam to TNT plant - 1268 BTU per lb.
1006 BTU per lb. of water to heat water to attain 80°C
Coal - $38.000 per ton or $0.019 per lb.

$$\frac{2225 \text{ lb } H_2O\text{/hr} \times 24 \text{ hr/day} \times 1006 \text{ BTU/lb } H_2O \times \$0.019\text{/lb coal}}{100{,}000 \text{ lb. TNT/day} \times 1268 \text{ BTU/lb Steam} \times 7.5 \text{ lb. steam/lb. coal}} = \$0.001073\text{/lb. TNT}$$

Steam will be used initially with each start-up to heat each of the purification vessels and interconnecting lines. The amount of steam is considered negligible and not considered in these costs.

Cooling Water

786 gal/min of cooling water is used to cool the entire manufacturing process. Only 25 percent of this is used in the purification phase.

$$\frac{786 \text{ gal/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times .25 \text{ percent} \times \$0.00013\text{/gal } H_2O}{100{,}000 \text{ lb. TNT/day}} = \$0.0003678\text{/lb. TNT}$$

Depreciation - 10-year straight line depreciation on investment capital cost

Building and Services	\$228,000
Process Equipment	456,000
Process Piping	110,000
Instrument	56,000
Electrical Instruments, etc.	62,000
	\$912,000

$$\frac{\$912{,}000/\text{capital cost}}{10\text{-yr/capital cost} \times 350 \text{ day/yr} \times 100{,}000 \text{ lb. TNT/day}} = \$0.002602/\text{lb. TNT}$$

Chemicals

Magnesium sulfite - System requires 440 lb/hr for pH control and purification.

$$\frac{MgO = 440 \text{ lb/hr} \times 24 \text{ hr/day} \times 40.32 \text{ (m.wt. of MgO)} \times \$1.10/\text{lb MgO}}{212.482 \text{ (m.wt. of } MgSO_3.6H_2O) \times 100{,}000 \text{ lb. TNT/day}} = \$0.02204/\text{ lb. TNT}$$

$$\frac{S = 440 \text{ lb/hr} \times 24 \text{ hr/day} \times 32.066 \text{ (m.wt. of S)} \times \$0.029622/\text{lb S.}}{212.482 \text{ (m.wt. of } MgSO_3 \cdot 6H_2O) \times 100{,}000 \text{ lb. TNT/day}} = \$0.0004721/\text{lb. TNT}$$

$$\frac{H_2O = 440 \text{ lb/hr} \times 24 \text{ hr/day} \times 108.096 \text{ (m.wt. of } H_2O) \times \$0.00013/\text{gal}}{212.482 \text{ (m.wt. of } MgSO_3.6H_2O) \text{ } 100{,}000 \text{ lb. TNT/day} \times 8 \text{ lb. } H_2O/\text{gal}} = \$0.0000008730/\text{lb. TNT}$$

Water used in dilution, tank, etc.

#2 Post Sellite Washer	1071 lb/hr
Day Tank	440 lb/hr
#2 Acid Washer	714 lb/hr
	2225 lb/hr

$$\frac{2225 \text{ lb } H_2O/\text{hr} \times 24 \text{ hr/day} \times \$0.00013/\text{gal}}{100{,}000 \text{ lb TNT/day} \times 8 \text{ lb } H_2O/\text{gal}} = \$0.000008678/\text{lb. TNT}$$

100 percent of chemicals recovered and credited under Recovery Section

Sub Total = \$0.02252/lb. TNT

Residue Loss @ \$0.40/lb.

Magnesium Sulfite Purification system has a 1.0 percent α-TNT loss.
50 ton per day rate equals 101,000 lb/day of crude TNT

$$\frac{101{,}010 \text{ lb. crude TNT/day} \times .01 \text{ percent} \times \$0.40/\text{lb crude TNT}}{100{,}000 \text{ lb. TNT/day}} = \$0.004040/\text{lb. TNT}$$

Maintenance - 5 percent of the capital investment is used for maintenance

$$\frac{\$912,000 \text{ x } .05 \text{ percent/yr}}{100,000 \text{ lb TNT/day x } 350 \text{ day/yr}} = \$0.001303$$

Total = $0.03240/lb. TNT

b. Recovery

Labor - The recovery operation requires 17 operators for a total of \$380,479.61/year minus \$55,479.61 for overhead and fringe benefits.

$$\frac{\$325,000.00/\text{year}}{350 \text{ days/year} \times 100,000 \text{ lb. TNT/day}} = \$0.009286/\text{lb. TNT}$$

Electricity

$$\frac{\$50,000.00/\text{year}}{350 \text{ days/year} \times 100,000 \text{ lb. TNT/day}} = \$0.001429/\text{lb. TNT}$$

Steam

$$\frac{\$27,853.47/\text{year}}{350 \text{ days/year} \times 100,000 \text{ lb. TNT/day}} = \$0.0007958/\text{lb. TNT}$$

Cooling Water

$$\frac{1225 \text{ gal/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times \$0.00013/\text{gal}}{100,000 \text{ lb. TNT/day}} = \$0.002153/\text{lb. TNT}$$

Compressed Air

$$\frac{\$1,423.17/\text{year}}{350 \text{ day/year} \times 100,000 \text{ lb. TNT/day}} = \$0.00004066/\text{lb. TNT}$$

Depreciation - 10-year straight line depreciation on capital investment.

$$\frac{\$4,336,000/\text{estimate}}{350 \text{ day/year} \times 100,000 \text{ lb./day} \times 10\text{-year/estimate}} = \$0.01239/\text{lb. TNT}$$

Chemical credit for recovery

100 percent - chemical recovery of Magnesium Sulfite

\$0.02252/lb. TNT x 1.00 = \$0.02252/lb. TNT

Maintenance - 5 percent of Capital investment

$$\frac{\$4,336,000/\text{estimate} \times .05 \text{ percent estimate/yr}}{350 \text{ day/year} \times 100,000 \text{ lb. TNT/day}} = \$0.006194/\text{lb. TNT}$$

* Fuel

Natural Gas for Start-Up

$$\frac{2167 \text{ cu. ft./hr} \times 24 \text{ hr/day} \times \$0.00193/\text{ cu. ft.}}{100{,}000 \text{ lb. TNT/day}} = \$0.001004$$

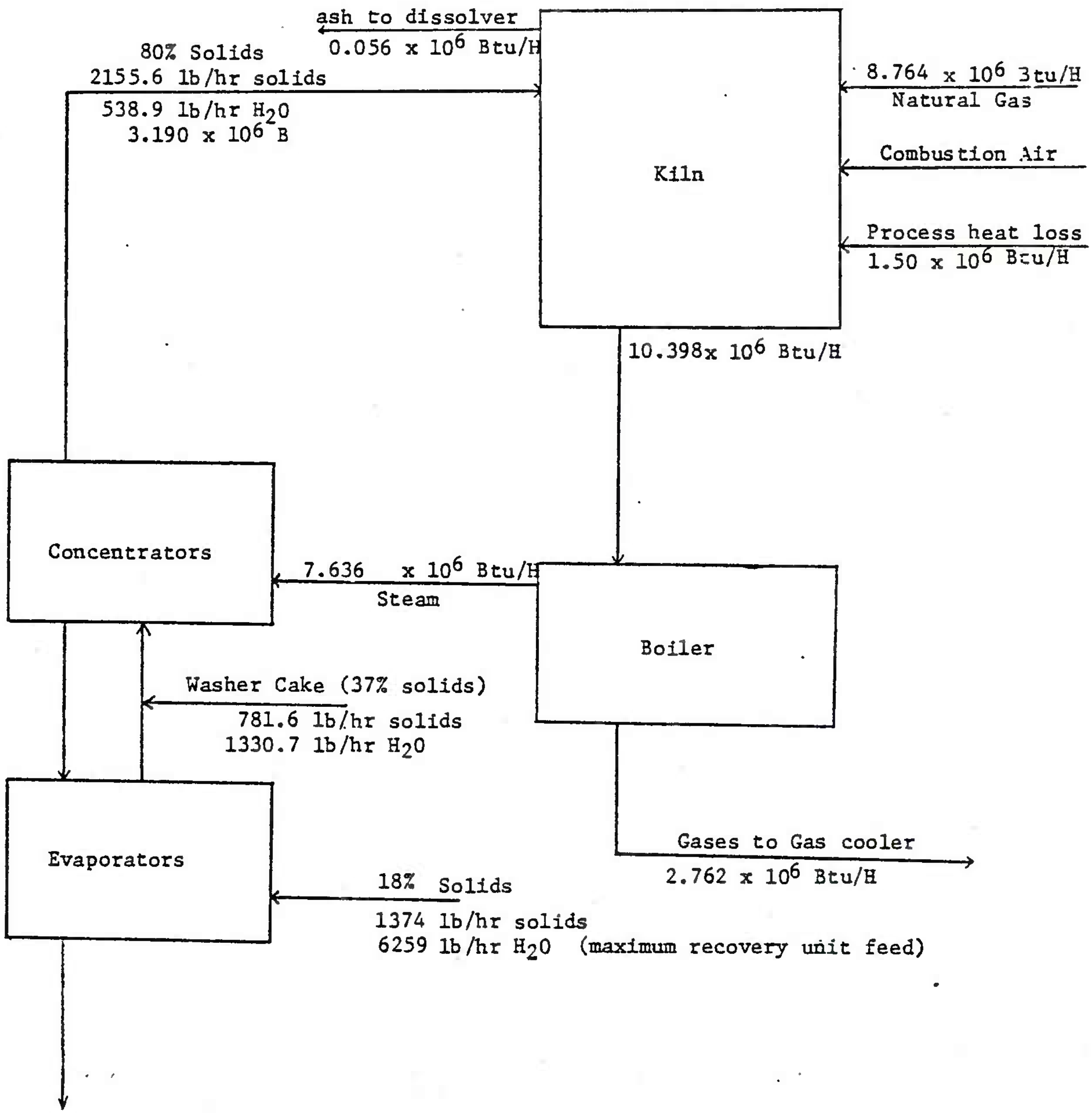
Natural Gas to evaporate Red water

$$\frac{14{,}906{,}452.2 \text{ BTU/hr} \times 24 \text{ hr/day} \times \$0.00193/\text{cu. ft.}}{1868 \text{ BTU/cu. ft.} \times 100{,}000 \text{ lb. TNT/day}} = \$0.004059$$

Sub Total	= $0.005063 lb. TNT
Total Cost	= $0.03735 lb. TNT
Total Cost minus Recovery	= $0.01483 lb. TNT

* See Figure C-1 for Energy

Energy Efficiency in the Recovery Process[1]



Heat available

1374 lb/hr Solids
2322 Btu/lb
3,190,428 Btu/hr available

.056 x 10^6 Btu/H ash
1.50 x 10^6 Btu/H Process Heat Loss
2.762 x 10^6 Btu/H Gases Cooler

Heat required to evaporate H_2O

6,259 lb/hr
+ 1,330.7 lb/hr
7,590 lb/hr H_2O
x 1006 Btu/lb
7,635,540 Btu/hr Required

$$\frac{8{,}763{,}540 \text{ Btu/hr} \times 24 \text{ hr/day} \times \$0.00193/\text{ cu. ft.}}{1000 \text{ Btu/ cu. ft.} \times 100{,}000 \text{ lb TNT/day}} = \$0.004059 \text{ / lb. TNT}$$

1Capacity for 2 TNT Lines)

Figure C-1

Appendix D
Cost Data for the
Leonard Continuous TNT Purification Process

1. Capital Costs

a. Purification

Item		Cost in dollars
Major Equipment		$466,000
Foundations		41,000
Structures		62,000
Buildings and Barricades		290,000
Piping S/S		207,000
Piping C/S		83,000
Instruments		207,000
Electrical		145,000
Insulation, Painting, Miscellaneous		62,000
	Sub Total	$1,563,000
Corps. of Engineers 8.8 percent		138,000
Contingency 10 percent		156,000
Construction fee 10 percent		156,000
Detailed and Process Engineering 25 percent		391,000
	Sub Total	$841,000
	Total	$2,404,000

1 Costs in this estimate were taken from an engineering study entitled "Engineering Study of The Adoption of Continuous Nitric Acid Purification To Continuous TNT Production Facilities" (CIL Process) prepared by The Leonard Process Co., Inc. These figures were escalated to 1978 costs.

2 Includes miscellaneous equipment such as hot water tanks and pumps, ion exchange water system and carbon bed filter.

b. Recovery

Item			Cost in dollars
Major Equipment			$166,000
Foundations			21,000
Structures			21,000
Building			41,000
Piping S/S			72,000
Piping C/S			31,000
Instruments			52,000
Electrical			41,000
Insulation, Painting, Miscellaneous			41,000
		Sub Total	$486,000
Corps. of Engineers	8.8 percent		43,000
Contingencies	10 percent		49,000
Construction fee	10 percent		49,000
Detailed & Process Engineering	25 percent		122,000
		Sub Total	$263,000
		Total	$749,000/line

Brodie Purifier [1]
Prices based on 1976 figures escalated to 1978

Item			
Brodie Purifier			$251,000
Commissioning Fee			4,000
Contractors Fee			50,000
		Sub Total	$305,000
Site Preparation and Purifier Structure			75,000
Hold Tank (for incinerates)			4,000
Miscellaneous (Piping, insulation, etc.)			20,000
		Sub Total	$99,000
Corps. of Engineers	8.8 percent		36,000
Contingencies	10 percent		40,000
Construction Fee	10 percent		40,000
Detailed & Process Engineering	25 percent		101,000
		Sub Total	$217,000
		Total	$621,000

[1] This unit will yield a total product of 200,000 lb/month and therefore will easily handle 2 TNT lines. Each TNT line, at a 50 TPD production rate will produce 75,000 lb/month TNT for recovery in the Brodie Purifier. (2 lines)

Incineration of Wastes

Item			Cost in dollars
Control Houses			271,000
Incinerator			445,000
Grinder Bldg.			461,000
Gas Analysis Bldg.			150,000
Pump Station House			58,000
Spray Pond			55,000
Settling Ponds			24,000
Barricades (3)			138,000
Site Improvements (8 acres, clear, grade, feed)			110,000
Roads untreated			20,000
Process Piping			202,000
Fuel Storage Tansk (2-26,500 Gal., 1-1500 Gal.)			80,000
Water Lines			231,000
Gas Pipe Line (2")			3,000
Pipe Line U/G (1 1/2")			2,000
Exterior lighting (12)			9,000
Distribution Transformers			12,000
Control Cables			115,000
Fire Alarm System			40,000
Storm Sewer			46,000
		Sub Total	$2,472,000
Corps. of Engineers	8.8		218,000
Contingency	10		247,000
Construction fee	10		247,000
Detailed & Process Engineering	25		618,000
		Sub Total	$1,330,000
		Total	$3,802,000

NOTE: This incinerator will handle 550 lbs. of waste per hour. Each 50 TPD line will produce 202 lb/hr. for the incinerator.

Escalated to 1978 prices based on 1977 figures (1.153)

2. Operating Costs

a. Purification

Labor - No additional operating labor should be required beyond the two operators per shift required for the nitration and purification operation.

Electricity	HP
Solution tank	1.5
7 crystallizers	40.0
2 screens	7.5
4 TNT wash tanks	7.0
Pumps	30.0
	86.0

$$\frac{86\text{ HP/HR} \times 24\text{ HR/day} \times .7457\text{ KWH/HP} \times \$0.02725\text{/KWH}}{100{,}000\text{ lb. TNT/day}} = \$0.0004196\text{/lb. TNT}$$

Steam	lb. steam/hr.
HNO_3 preheater	1,300
4 Wash tanks & Separators	850
Wash water heating	2,000
	4,150

$$\frac{4{,}150\text{ lb. steam/hr} \times 24\text{ hr/day} \times \$0.00325\text{/lb. steam}}{100{,}000\text{ lb. TNT/day}} = \$0.003237\text{/lb. TNT}$$

Cooling Water	GPM
Solution Tank	40
7 crystallizers	225
Wash water	35
	300

$$\frac{300\text{ gal/min.} \times 50\text{ min/hr} \times 24\text{ hr/day} \times \$0.00013\text{/gal}}{100{,}000\text{ lb. TNT/day}} = \$0.0005615\text{/lb. TNT}$$

Process Water

18,000 lb/hr or 1,620 gal/hr required

$$\frac{1620\text{ gal/hr} \times 24\text{ hr/day} \times \$0.00054\text{/gal}}{100{,}000\text{ lb. TNT/day}} = \$0.0002100\text{/lb. TNT}$$

Nitric Loss

269.0 lb/hr lost in eash system

$$\frac{269.0\text{ lb/hr} \times 24\text{ hr/day} \times \$0.10966/\text{lb.}}{100{,}000\text{ lb. TNT/day}} = \$0.007080/\text{lb. TNT}$$

TNT Loss

303 lb/hr to be incinerated 50 percent of this is α-TNT

$$\frac{303\text{ lb TNT/hr} \times 24\text{ hr/day} \times \$0.40/\text{lb TNT} \times .50}{102{,}400} = \$0.01420/\text{lb. TNT}$$

Depreciation

10-year straight line depreciation on
capital investment

$$\frac{\$2{,}404{,}000/\text{investment}}{100{,}000\text{ lb. TNT/day} \times 350\text{ day/yr} \times 10\text{-yr investment}} = \$0.006869/\text{lb. TNT}$$

Fuel - None

Maintenance - 5 percent of capital investment

$$\frac{\$2{,}404{,}000/\text{investment} \times .05\text{ investment/yr}}{100{,}000\text{ lb. TNT/day} \times 350\text{ day/yr}} = \$0.003434/\text{lb. TNT}$$

Total $0.03601/lb. TNT

b. Recovery

1. Nitric Acid Recovery

Labor - No additional labor required

Electricity - 10 HP (required)

$$\frac{\text{10 HP/hr x 24 hr/day x .7457 KWH/HP x \$0.02725/KWH}}{\text{100,000 lb TNT/day}} = \text{\$0.00004879/ lb. TNT}$$

Steam 11,000 lb/hr (required)

$$\frac{\text{11,000 lb/hr x 24 hr/day x \$0.00325/lb.}}{\text{100,000 lb. TNT/day}} = \text{\$0.008580/ lb. TNT}$$

Cooling Water 1,000 gal/min (required)

$$\frac{\text{1000 gal/min x 60 min/hr x 24 hr/day x \$0.00013/ gal}}{\text{100,000 lb. TNT/day}} = \text{\$0.001872/ lb. TNT}$$

Depreciation 10-year straight line depreciation on capital

$$\frac{\text{\$749,000/capital investment}}{\text{100,000 lb TNT/day x 350 day/yr x 10-yr/capital investment}} = \text{\$0.002140/ lb. TNT}$$

Maintenance 5 percent of capital costs

$$\frac{\text{\$749,000/capital investment x .05 capital invest./yr.}}{\text{100,000 lb. TNT/day x 350 day/yr.}} = \text{\$0.001070/ lb. TNT}$$

Nitric Acid Loss 5 lb/hr in process

$$\frac{\text{5 lb/hr } HNO_3 \text{ loss x 24 hr/day x \$0.10966/lb } HNO_3}{\text{100,000 lb TNT/day}} = \text{\$0.0001316/ lb. TNT}$$

TOTAL = \$0.01384/ lb. TNT

2. Brodie Purifier

Labor - Brodie Purifier requires 1/2 man per shift

$$\frac{4\ \text{hr/shift} \times 3\ \text{shifts/day} \times \$6.74/\text{hr}}{100{,}000\ \text{lb. TNT/day}} = \$0.0008088/\text{lb. TNT}$$

Electricity 6 KWH (required)

$$\frac{6\ \text{KW/hr} \times 24\ \text{hr/day} \times \$0.02725/\text{KWH}}{100{,}000\ \text{lb. TNT/day}} = \$0.00003924/\text{lb. TNT}$$

Steam 55 lb/hr (required)

$$\frac{55\ \text{lb steam/hr} \times 24\ \text{hr/day} \times \$0.00325/\text{lb. steam}}{100{,}000\ \text{lb. TNT/day}} = \$0.00004290/\text{lb. TNT}$$

Cooling System - required 60,000 Btu/hr

$$\frac{60{,}000\ \text{Btu/hr} \times 24\ \text{hr/day} \times \$0.019/\text{lb coal}}{100{,}000\ \text{lb TNT/day} \times 1268\ \text{Btu/lb. steam} \times 7.5\ \text{lb. steam/lb. coal}} = \$0.00002877/\text{lb. TNT}$$

Process Water 2,060 lb/hr (required)

$$\frac{2060\ \text{lb/hr} \times 24\ \text{hr/day} \times \$0.00013/\text{gal.}}{100{,}000\ \text{lb TNT/day} \times 8\ \text{lb./gal.}} = \$0.000008034/\text{lb. TNT}$$

TNT Loss *(credit) 101 lb/hr recovered

$$\frac{101\ \text{lb/hr} \times 24\ \text{hr/day} \times \$0.40/\text{lb}}{100{,}000\ \text{lb. TNT/day}} = *\$0.009696/\text{lb. TNT}$$

Maintenance 5 percent of capital investment

$$\frac{\$621{,}000/\text{cap. Inv.} \times .05\ \text{cap. Inv/yr}}{100{,}000\ \text{lb. TNT/day} \times 350\ \text{day/yr}} = \$0.0008871/\text{lb. TNT}$$

Depreciation 10-yr on capital investment

$$\frac{\$621{,}000/\text{capital investment}}{100{,}000\ \text{lb. TNT/day} \times 350\ \text{day/hr} \times 10\text{-yr/cap. Inv.}} = \$0.001774/\text{lb. TNT}$$

Credit Total $0.006107/lb. TNT

3. Incineration

Labor 3 wage per shift per day, 4 shifts continuous

$$\frac{\text{3 wage/shift 8 hr/wage x 3 shifts/day x \$6.74/hr}}{\text{100,000 lb. TNT/day}} = \text{\$0.004853/lb. TNT}$$

Electricity 120 HP (Required)

$$\frac{\text{120 HP/hr x 24 hr/day x .7457 KWH/HP x \$0.02725/KW}}{\text{100,000 lb. TNT/day}} = \text{\$0.0005855/lb. TNT}$$

Steam - None

Cooling Water 7 gal/min (required) (required)

$$\frac{\text{7 gal/min x 60 min/hr x 24 hr/day x \$0.00013/gal.}}{\text{100,000 lb. TNT/day}} = \text{\$0.00001310/lb. TNT}$$

Process Water 25 gal/min (required)

$$\frac{\text{25 gal/min x 60 min/hr x 24 hr/day x \$0.00013/gal}}{\text{100,000 lb. TNT/day}} = \text{\$0.00004680/lb. TNT}$$

Nitric Acid Loss - None

TNT Loss - counted in operating costs

Maintenance 5 percent of capital investment

$$\frac{\text{\$3,802,000/capital investment x .05 cap. Inv.}}{\text{100,000 lb. TNT/day x 350 day/yr}} = \text{\$0.005431/lb. TNT}$$

Depreciation - 10-yr. straight line based on Capital Investment

$$\frac{\text{\$3,802,000/capital investment}}{\text{100,000 lb. TNT/day x 350 day/yr x 10-yr/cap. invest.}} = \text{\$0.01086/lb. TNT}$$

Fuel/Oil 28 gal/hr (required)

$$\frac{\text{28 gal/hr x 24 hr/day x \$0.464/gal}}{\text{100,000 lb. TNT/day}} = \text{\$0.003118/lb. TNT}$$

Natural Gas 50 gal/month

$$\frac{\text{50 gal/month x \$0.001359/ cu. ft.}}{\text{30 days x 100,000 lb. TNT/day x 7.5 gal/ cu. ft.}} = \text{\$0.00000000302/lb. TNT}$$

Sub Total $0.003118

Total $0.02491/lb. TNT

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